Mesoscale Analysis and Forecasting

1b. Determine the cause, type, and characteristics of flight level hazards.

Turbulence

- The irregular movement of air in the atmosphere resulting in the creation of eddy currents and windshear
- These eddies can create rapid fluctuations in vertical and horizontal velocities of aircraft with effects ranging from minor discomfort to possible structural damage

Turbulence

- Effects on aircraft
  - The amount of turbulence experienced by fixed wing aircraft is
    - Directly proportional to the aircraft speed
    - Directly proportional to the wing area
    - Inversely proportional to the weight of the aircraft

Turbulence

- The amount of turbulence experienced by rotary wing aircraft is
  - Directly proportional to the aircraft speed.
  - Directly proportional to the arc of the rotor blade (wing area).
  - Inversely proportional to the weight of the aircraft.
  - Inversely proportional to the lift velocities

Turbulence

- Effect on specific aircraft
  - All Air Force Weather Agency's (AFWA) Global Weather Center Division turbulence forecasts and TAF's are issued for Category II aircraft
  - Pilot Reports (PIREPS) of turbulence are for the aircraft type reporting it
  - To convert forecasts and PIREPS to correspond with specific aircraft type refer to AFGWC TN 79/001, Appendix A, Tables A-1 and A-2
  - You must know the specific aircraft type and what hazards the aircraft is capable of handling

TURBC/ACFT Category

TURBC FCST/PIREP Conversion

Turbulence

- Types of turbulence
  - Convective turbulence
    - It is localized vertical currents due to either intense surface heating over an uneven terrain or the convective currents associated with cumuliform clouds
    - Thermally-induced convective turbulence (may or may not be associated with cumuliform clouds)
      - Normally found from the surface to the top of the boundary layer, but may also be found in upper levels (in association with cumuliform clouds)
      - Caused by uneven heating on the surface causing alternating currents of ascending and descending air

Turbulence

- Conditions that are favorable for the formation of thermally-induced convective turbulence
  - » Warm summer afternoons with clear to partly cloudy skies
  - » Light winds (strong winds break up the convective currents)
  - » Uneven terrain with different types of surfaces (e.g., barren surfaces heat up more than water or vegetation covered surfaces)

Turbulence

- Effects on aircraft during landing
  - » Updrafts may cause pilot to overshoot runway
  - » Downdrafts may cause pilot to undershoot runway
- Thermally-induced convective turbulence is usually light to moderate in intensity

Turbulence

- Thunderstorm-induced convective turbulence
  - 1 The most hazardous type of convective turbulence
  - 2 Can be experienced beneath, in the clouds or above the clouds
  - 3 The greatest probability of severe convective turbulence normally occurs within the cloud, within 10,000 - 15,000 ft AGL, and/or within 5,000 ft of the freezing level
  - 4 Thunderstorm induced convective turbulence is usually moderate to extreme in intensity

Turbulence

- Low-level mechanical turbulence
  - It is caused by wind shear, which is caused by pressure gradient differences, terrain obstructions, or frontal zone shear
  - The degree of low-level mechanical turbulence is a function of
    - Wind speeds at the surface, including gusts
    - Terrain roughness (rough terrain is defined as a region where topographic features extend more than 1,000 feet above the surroundings)
    - Stability of the atmosphere from the surface to 850 mb

Turbulence

- Unstable air allows larger eddies to form than those in stable air; but the instability breaks up the eddies quickly, while in stable air they dissipate slowly
- Low-level, vertical wind shear associated with frontal boundaries

- Forecasting low-level mechanical turbulence
  - 1 Rules are found in AWSP 105-56, pages 4-2.3-1 and 4-2.4-1
  - 2 Refinements based on PIREPS, wind shear, surface pressure change, time of day, surface heating, local terrain effects, and aircraft configuration should be made

Low level Mechanical TURBC FCST Rules

Turbulence

- Mountain wave turbulence (high-level mechanical)
  - This type occurs when stable air flows across a mountain range
  - The most dangerous type of mechanical turbulence
    - Mainly due to the very high velocity updrafts and downdrafts on the lee side of the mountain range
    - The updrafts and downdrafts may extend as high as 70,000 feet and as far as 300 miles downstream from the mountain range

Turbulence

- Conditions favorable for the formation of mountain wave turbulence
  - A perpendicular component of the wind across the top of the mountain of 25 knots or greater
  - A wind direction within 45˚ of perpendicular across the mountain top
  - A stable layer at and above the mountain tops

Turbulence

- Other clues for mountain wave potential
  - A temperature of -70°C or less in the upper atmosphere (200 mb) near the mountain wave zone
  - Rapidly falling pressures to the lee side of mountains
  - Lee side gusty surface winds at nearly right angles to the mountains
  - Blowing dust picked up and carried aloft to 20,000 feet AGL or higher
  - The presence of rotor clouds
  - Broken or ragged-edge ACSL reported on the lee side of the mountains

Turbulence

- Clouds often associated with mountain w ave turbulence
  - Cap cloud
    - » Low hanging cirriform or stratiform type clouds with its base near the mountain top and at times obscuring the mountain peak
    - » Most of the cloud is on the windward side with part of the cloud flowing down the lee side
    - » Usually associated with *severe* turbulence

Mountain Wave clouds

Cap cloud

Turbulence

- Rotor cloud
  - » An altocumulus type line of clouds parallel to the ridge line on the lee side of the mountain range
  - » The cloud is usually stationary and is constantly forming and dissipating on the lee side
  - » The air in the cloud rotates around a horizontal axis parallel to the mountain range
  - » The most dangerous features of mountain waves are the extreme turbulence in and below the rotor clouds which can reach up to 5,000 feet per minute

Mountain wave clouds – Rotor clouds

Turbulence

- Lenticular cloud
  - » Lens or almond shaped clouds that are the most frequent cloud associated with mountain waves
  - » Like the rotor cloud, they are stationary, constantly forming clouds that are located parallel to, and on the lee side of mountain ranges
  - » They normally form above rotor clouds and are usually found above 20,000 feet
  - » Associated with moderate to severe turbulence

Mountain wave clouds – Lenticular clouds

Turbulence

- Clear Air Turbulence (CAT)
  - Turbulence that is not associated with convective clouds or thermally induced. CAT is not restricted to cloud-free air
  - It can also occur in cirrus clouds and haze layers

Turbulence

- Synoptic weather patterns
  - Synoptic wind pattern (jet stream)
    - » CAT is found in areas of greatest horizontal and vertical speed shear
    - » For CAT occurrence, the horizontal wind shear should be > 40 knots/150 nm and the vertical wind shear should be > 6 knots/1000 ft
    - » Most common areas in association with the jet stream are found where isotach gradients are strong

Turbulence

- Thermal Patterns
  - Cold-air advection associated with temperature gradients at the 300, 250, and 200 mb levels provide key information for the potential of CAT
  - Expect CAT when a temperature gradient of 5°C/120 nm exists or is forecast and at least one of the following is observed
    - » A trough is present and moving > 20 knots
    - » Horizontal wind shear > 35 knots /200 km (≈120 nm)
    - » Wind component normal to the cold advection > 55 knots
    - » A wind shift > 75° in the region of cold-air advection

Turbulence

- Upper-level ridges
  - Moderate CAT can be expected on both sides of an anticyclonically curved jet, where it undergoes maximum latitudinal displacement in an amplifying ridge
  - Maximum CAT is in the area of greatest anticyclonic curvature (usually within 250 nm of the ridge axis and elongated in the direction of the flow)
  - Expect moderate to severe CAT with
    - » Strong vertical wind shear > 10 knots/1000 ft
    - » Winds > 135 knots in an area of large anticyclonic curvature
    - » Winds >115 knots in an area of strong latitudinal displacement (Steep LWR)

CAT/Upper level ridges

Turbulence

- Surface cyclogenesis
  - When cyclogenesis occurs, CAT should be forecast near the jet stream core north-northeast of the surface low
  - CAT intensity is directly related to the rate of cyclogenesis
    - » If deepening is > 1 mb/hr expect moderate to severe turbulence
    - » If deepening is < 1 mb/hr expect moderate turbulence
  - CAT intensity is also related to the proximity to the mountains, intensity of the jet core, and the intensity of the downstream ridge

CAT/ Surface cyclogenesis

Turbulence

- Confluent jets
  - When two jet stream cores converge within 300 nm (5° latitude), the potential for CAT increases
  - Strong vertical wind shear will be produced if the poleward jet undercuts the second jet

CAT/Confluent jets

Turbulence

- Upper-level lows
  - As a cut-off low develops, there is a potential for moderate CAT
  - During the cut-off process, CAT is found in areas of confluent and difluent flow
  - Once the low is cut-off, the intensity of CAT will diminish to "light" in the area of the low

CAT/Upper level lows

Turbulence

- Shear line in throat of upper-air low
  - When the jet is strong around a closed low and there is a narrow neck between the prevailing flow around the low, there is a potential for moderate CAT if wind speeds > 50 knots.
  - If winds reach 115 knots, forecast moderate to severe CAT
  - The potential for CAT is greater between the two anticyclonically curved portions of the jet

CAT/Shear Line

Turbulence

- Difluent wind patterns
  - Most CAT occurrences are observed during the formation of the difluent patterns
  - After the difluent pattern is established, the CAT weakens in the difluent zone
  - When difluent wind patterns exist aloft, the probability of CAT is low, except when a surface front is present

CAT/Difluent wind Pattern

Turbulence

- Shearing trough
  - Rapidly moving troughs north of a quasi-stationary jet produce a CAT potential in confluent flow at the base of the trough
  - The area of CAT is just north of the jet stream core and on the downwind side of the southern portion of the trough line

CAT/Shearing Trough

Turbulence

- Strong wind maximum to the rear of an upper trough
  - When a strong north-south jet is located along the back side of an upper trough, the potential for CAT is high
  - The potential for CAT is in the area of decreasing winds between the base of the trough and the max wind upstream, and should be centered on the warm air (equatorward) side of the jet stream core
    - » The change of wind speed should be > 40 knots within 10° latitude for CAT to occur.
    - » If a difference of at least 60 knots exists between the jetstream core minimum in the trough and a point in the jetstream core 10° latitude upstream, forecast moderate or greater turbulence.

CAT/Strong wind max behind upper trough

Turbulence

- 500-mb
  Clear Air Turbulence criteria
  - The 500-mb chart is a useful tool to check for CAT potential
  - However, exclusive use of one chart is not recommended; data for all available levels should be considered

500 mb TURBC indicators

Turbulence

- General clues to consider for the existence of CAT
  - A definite thermal trough (cold air tongue)
  - A moving, closed isotherm pattern (often seen before contours close off)
  - Strong 500-mb winds (> 75 knots) along with a wind direction shift > 20º and a strong thermal gradient
  - Troughs associated with surface frontal waves
  - Narrow band of strong winds with strong horizontal wind shears
  - A double contour trough at 500 mb

- Specific 500 mb synoptic situations are describe in AWSP 105-56

Turbulence

- Determine turbulence intensities based on horizontal and vertical speed shear
  - The following table is used for estimating the potential for various turbulence intensities (based on Category II aircraft)

Intensity	Horizontal Shear	Vertical shear
Light	< 25 kt/ 90 nm	3-5 kt/ 1000 ft
Moderate	25-49 kt/ 90 nm	6-9 kt/ 1000 ft
Severe	50-89 kt/ 90 nm	10-15 kt/ 1000 ft
Extreme	> 90 kt/90 nm	> 15 kt/ 1000 ft

Turbulence

- Examples:
  - Horizontal (diagram needed)
  - Vertical (diagram needed) see hardcopy lesson plan

Turbulence

- Occurrence of Intensities
  - Light turbulence causes small changes in the aircraft's attitude and/or altitude
    - Low-level mechanical turbulence
    - In or near fair weather cumulus clouds
    - Near the tropopause without the presence of a strong jet

Turbulence

- Moderate turbulence causes moderate changes experienced in aircraft attitude and/or altitude, but aircraft remains in positive control at all times with small variations in airspeed are experienced
  - Mountain wave turbulence
    - Perpendicular wind component > 50 knots at the mountain range, moderate turbulence will be experienced up to 300 nm downstream from the mountain’s ridge line
    - Perpendicular wind component 25 - 50 knots, moderate turbulence will be experienced up to 150 nm
    - In or near ACSL

Turbulence

- In, near, and above thunderstorm and TCU
- Near the jet stream cores (cold side, above and below core)
- In upper cold troughs
- Low-level mechanical turbulence
- Thermal turbulence

Turbulence

- Severe turbulence causes abrupt changes in aircraft's attitude and/or altitude; aircraft may be out of control for short periods of time along with large variations in airspeed
  - Mountain wave turbulence
    - Perpendicular wind component > 50 knots at the mountain range, severe turbulence will be experienced up to 150 nm downstream
    - Perpendicular wind component 25 -50 knots at the mountain range, severe turbulence will be experienced up to 50 nm
    - Associated with Cap clouds and ACSL

Turbulence

- In or near mature thunderstorms
- Near jet streams characterized by: Vertical shears > 10 knots/1000 ft and/or horizontal shears > 50 knots/90 nm

– Extreme turbulence causes the aircraft to be violently tossed about and practically impossible to control with structural damage

- Mountain wave turbulence - in or near rotor clouds
- In or near severe thunderstorms

Low-Level Wind Shear (LLWS)

- LLWS is a change in wind speed and/or direction over a short distance, which results in a tearing or shearing action
- It is particularly hazardous when it happens over a short period of time, within 2,000 feet of the ground during take-offs and/or landings

Low-Level Wind Shear (LLWS)

- Effects on aircraft performance
  - Performance decreasing wind shear occurs when an aircraft flies from a headwind to a tailwind (or decreasing headwind) over a short period of time
    - The relative velocity of air over the wings decreases
    - The aircraft looses lift as a result
    - Its indicated airspeed decreases

Performance decreasing shear

Low-Level Wind Shear (LLWS)

- Performance Increasing Wind Shear occurs when an aircraft flies from a tailwind to a headwind (or increasing headwind)
  - The relative velocity of air over the wings increases
  - The aircraft increases lift as a result
  - Its indicated airspeed increases

Performance increasing shear

Low-Level Wind Shear (LLWS)

- Favorable conditions for LLWS
  - Thunderstorm gust front (outflow boundary)
    - LLWS is assumed to exist whenever thunderstorms are observed or forecasted within 10 nm of the airfield
    - The greatest threat is at the leading edge of the gust front

Low-Level Wind Shear (LLWS)

- High-level (base) thunderstorms
  - Present primarily in the western and southwestern U.S.
  - Necessary conditions which indicate the potential for low-level wind shear from high base thunderstorms include *all* of the following:
  - Convective clouds with bases > 8,000 ft AGL
  - Surface temperature > 80°F, along with a dew point depression > 40°F

Low-Level Wind Shear (LLWS)

- Virga, rainshowers, or thunderstorms within 10 nm of the airfield
- These conditions result in the formation of strong downrush winds (downbursts) which produce LLWS

Low-Level Wind Shear (LLWS)

- Frontal Boundaries
  - Wind direction and speed changes across frontal slopes create low-level wind shear
  - Greatest potential associated with fronts is
  - Up to 6 hours in advance of warm frontal passage
  - Up to 2 hours after cold frontal passage
  - Forecast LLWS if *any or all* of the following criteria are associated with a frontal boundary approaching or passing your station

Low-Level Wind Shear (LLWS)

- A vector wind difference across the front with a magnitude >20 knots/50 nm
- A temperature difference across the front >10°F (5°C)/50 nm. The stronger the temperature gradient, the greater potential there is for low-level wind shear
- A frontal speed $\geq$ 30 knots

Low-Level Wind Shear (LLWS)

- Low-level jet (LLJ)
  - This phenomenon occurs frequently over the Central plains states during the summer, mostly during the night or early morning hours.
  - Forecast when the following criteria are met
    - Surface winds are 0-8 knots and increasing with height
    - Wind speeds of 25-40 knots or greater are present at approximately 650-1,500 ft AGL
    - Decreasing wind speeds with height to approach the gradient level wind speeds of 15-30 knots

Low-Level Wind Shear (LLWS)

- Wind shear can occur when the wind component normal to the top of the mountain range is 25 knots and winds are increasing with height
- Wind shear can occur at the leading edge of the land and/or sea breeze
- Gusty surface winds causes a sudden brief increase in the speed of the wind and you need to consider local terrain influences
- Wind shear can occur with a low-level inversion where there is light surface winds and a strong gradient level wind

Low-Level Wind Shear (LLWS)

- LLWS Forecast Checklist is located in the AWSP 105-56

LLWS Checklist

Icing

- Effects of aircraft icing
  - Ice on the airframe decreases lift and increase weight
  - Ice on exterior, moveable surfaces affects aircraft control surfaces
  - Ice on rotors and propellers can result in extreme vibrations
  - Ice in the air intake of an engine can rob the engine of air to support combustion

Icing

- Ice ingested into the engine can cause foreign object damage (FOD)
- Other effects include loss of aircrew's vision, instrument failure, etc.

Icing

- Formation of aircraft icing
  - Two basic conditions that must be met for the formation of aircraft icing
    - The free-air temperature on the aircraft surface must be <0°C
    - Super-cooled water droplets must be present
  - Most in cloud icing occurs with temperatures between 0 and -20°C
  - Icing is rare in clouds with temperatures < -20°C because these clouds are almost completely composed of ice crystals

Icing

- Types of aircraft icing
  - Clear is glossy, clear or translucent ice
    - Conditions favorable for the formation of clear ice include a high water content, large droplet size, and temperatures slightly below freezing, normally between 0°C and -8°C
    - Clear ice is most frequently encountered in cumuliform clouds and freezing precipitation

Icing

- Rime is rough, milky, opaque ice
  - Rime ice can form and accumulate at all temperatures <0°C
  - Rime ice is common in stable, stratiform clouds where temperatures are between 0°C and -15°C
  - Rime ice can also be found in cumuliform clouds where temperatures are < -15°C
- Mixed is a mixture of clear and rime ice and found most often in cumuliform clouds at temperatures between -9°C and -15°C

Icing

- Frost
  - Forms on exposed surfaces of parked aircraft when the temperature of the exposed surface is < 0°C (while the free-air temperature may be > 0°C)
  - Also can form on descending aircraft when it hit very humid air

Icing

- Aircraft icing and associated cloud types
  - Stratiform clouds
    - Icing is primarily encountered in the low and mid etage clouds and is confined to a layer between 3,000 and 4,000 ft thick
    - Icing intensities generally range from trace to light, with the maximum values occurring in the upper portions of the cloud where colder temperatures exist
    - The main hazard lies in the great horizontal extent of some of these cloud decks

Icing

- Both rime and mixed icing may be found in stratiform clouds, with rime usually the case
- Icing is rare in high-level stratiform clouds (cirriform) because these are mostly composed of ice crystals

Icing

- Cumuliform clouds
  - The zone of probable icing is smaller horizontally, but greater vertically than in stratiform clouds
  - All types of icing can be encountered in cumuliform clouds
  - Actual type depends on the stage of development and temperature of the cloud

Icing

- Aircraft Icing Intensities
  - Trace
    - Icing first becomes observable
    - Can be found at all temperatures 0°C to -40°C
    - Can occur at temperatures between 0°C and -7°C, with a dew-point depression of < 2°C and neutral or weak cold-air advection
    - Can occur at temperatures between -8°C and -15°C, with a dew-point depression of < 3°C and neutral or weak cold-air advection

Icing

- Light
  - Rate of accumulation requires the occasional use of deicing equipment
  - Generally found at temperatures between 0°C and -22°C in the cloud
  - Often found in showery precipitation
  - Often found in clouds up to 300 nm ahead of a warm front
  - Can occur at temperatures between 0°C and -7°C, with a dew-point depression of < 2°C and strong cold-air advection

Icing

- Can occur at temperatures between -8°C and -15°C, with a dew-point depression < 3°C and strong cold-air advection
- Associated with clouds, not due to frontal or orographical lift, over areas without steady non-freezing precipitation

Icing

- Moderate
  - Rate of accumulation requires the continuous use of de-icing equipment
  - Generally found at temperatures between 0°C and -15°C
  - Often found in clouds up to 100 nm behind a cold front
  - Associated with areas of freezing drizzle

Icing

- Severe
  - Rate of accumulation is too rapid for de-icing equipment to handle
  - Associated with areas of freezing rain
  - Can occur with all thunderstorms

- APPLICATION: Students will complete appraisals and answer questions in class
- EVALUATION: Written test at the end of the unit.